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Studies on Peat in the Coastal Plains of Sumatra and Borneo Part II: The Clay Mineralogical Composition of Sediments in Coastal Plains of Jambi and South Kalimantan

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Abstract

The clay mineralogical composition of sediments in the coastal plain of Jambi and South Kalimantan was studied in order to find support for field observations. The Pleistocene terrace underneath the deep peat in the coastal plain of Jambi shows a predominance of the 1:1 type clay minerals (7.2 Å). More recent sediments form uplifted tidal flats and mangrove deposits contain relatively higher amounts of the 14 Å minerals than the Pleistocene terrace, although kaolin minerals still dominate these sediments.

In South Kalimantan, the samples come only from recent sediments of tidal flats and mangrove deposits. Although all samples show a predominance of the 1:1 type clay minerals, they also contain appreciable amounts of 14 Å minerals. The amount of 14 Å minerals in recent sediments in South Kalimantan is higher than in Jambi.

The recent levee materials are characterized by illite (10 Å) and 14 Å minerals. These clay minerals were transported by the river from the hinterland as weathering products.

The transformation of clay mineral in the sediments was controlled by: (1) the sediment source, (2) the acid environment resulting from organic matter decomposition and pyrite oxidation, and (3) the marine environment.

I Introduction

In the former paper, the physiography and geomorphology of coastal plains of Jambi and South Kalimantan were studied in order to recognize the geomorphic units of each physiographic region. In Jambi, the geomorphic units established included: Pleistocene terrace underneath deep peat, natural levees along the rivers, sand ridges and tidal flats in the Holocene, and mangrove deposits, sometimes overlain by thin peat. In South Kalimantan, the sand ridges and tidal flats, and the mangrove deposits underneath the thin peat were also found. Pleistocene terrace underlying the deep peat was not found within the studied area of South Kalimantan, but sand and gravel occur here overlain by thin peat or mangrove deposits.

The sediments in these coastal plains originated as weathering products from the hinterland brought by the main rivers. It is also possible that marine action also influenced the deposition processes of sediments in the brackish to marine deposits zone. Likewise, the transgression and regression of the sea during

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the Post-Glacial period played an important role in the rapid change of coastline by alluvial deposition and in the rise of topography by the accumulation of organic matter. All these factors may control the transformation and preservation of clay minerals in the sediments. This is why we here emphasize the study of clay content with the aims of characterizing each geomorphic unit in terms of its clay mineralogical composition, which may reflect both weathering history and geomorphic processes. In this investigation, pyrite-bearing beds were also studied in order to clarify the relationship between the factor of acid environment, which is caused by the oxidation of pyrite, and the transformation of clay minerals.

The purpose of the present study on clay mineralogical characteristics of swampy sediments in Jambi and South Kalimantan is to support the field observation in the following points: (1) to distinguish the clay mineralogical composition of each geomorphic unit, and (2) to determine the controlling factors of clay mineral transformation.

Materials and Methods

To study the clay mineralogical composition of sediments in the study areas, samples were collected from layers at several observation points using the sub-sampling method, for which two-centimeter-thick samples were taken from each soil sample in plastic pipes at each layer in vertical sequence. The location of soil sampling sites was presented in the former paper [Supiandi 1988].

After the separation of the clay fraction and the preparation of an oriented specimen of clay [Jackson 1969], CuK_α-radiation was used for X-ray diffraction analysis. The X-ray diffraction patterns (XRD) were obtained for the potassium-saturated (K-clay) before and after heating and for magnesium-saturated (Mg-clay) with or without glyceration. According to Kawaguchi and Kyuma [1969], the relative abundance of kaolin, illite and other 2:1 and 2:2 clays in the clay fraction can be determined approximately by measuring the area of diffraction peaks of air-dried Mg-clays at $2\theta=12°$, 8.8°, and 6–5°, which are equivalent to the basal spacings of kaolin minerals (ca. 7 Å), illite (10 Å) and other 2:1 or 2:2 type minerals (14 Å minerals), respectively. This last includes smectite, vermiculite, chlorite, and Al-interlayered minerals. The collapse of the 14 Å peak of the air-dried Mg-clay to 12 or 10 Å of the air-dried K-clays shows the presence of smectite and vermiculite, respectively. The existence of smectite was also ascertained by a shift of the 14 Å peak to 18–19 Å for glycerated Mg-clay. The presence of Al-interlayered smectite and/or vermiculite is indicated by a shift of the 14 Å peak of the air-dried Mg-clay to 12 or 14 Å of K-clay after heating at 300°C and 500 to 550°C.

The proportions of smectite, vermiculite and Al-interlayered smectite and/or vermiculite are difficult to calculate, so the relative abundance of each species is shown by +, ++ or +++.

During the field study, the depth of sulfidic horizon was also recorded according to the presence of pyrite. To identify pyrite in the field, samples were oxidized with 30 percent of H_2O_2, and a drop of pH to below 2.0 was taken to indicate the presence of pyrite. To study the oxidation products of pyrite, samples characterized by pale yellow mottles were taken and analyzed by X-ray diffraction using CoK_α-

radiation. These samples were also observed under the scanning electron microscope.

Results and Discussion

Clay Mineralogical Composition

X-ray diffraction analysis was conducted on seven profiles from the coastal plains of Jambi and five from South Kalimantan. Several typical XRDs of soil clays from each physiographic region are presented in Fig. 1 and 2.

Jambi

Table 1 shows the clay mineralogical composition of sediments in each physiographic region, expressed by relative abundance of kaolin mineral (7 Å), illite (10 Å) and 14 Å minerals.

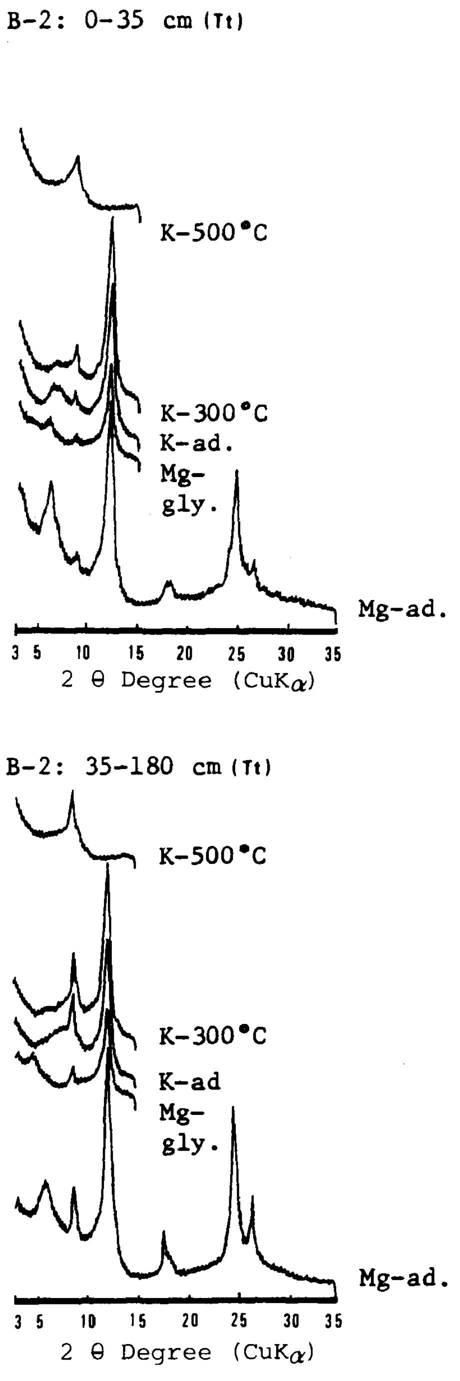
Table 1 The Clay Mineralogical Composition of Sediments from the Study Area of Jambi

Profile	Depth (cm)	Stratigraphic Type	EC* (µmho/cm)	Mineralogical Composition						Texture
				7 Å (%)	10 Å (%)	14 Å (%)	Sm	V	Al	
				Mineral Riverine Deposit Zone						
B- 2	0– 35	Tt	nd	70	10	20	–	+	+++	Light Clay
	35–180	Tt	nd	70	15	15	++	+	+	Light Clay
RTP- 1	0– 44	Tt	nd	70	15	15	+	+	++	Light Clay
	44–160	P	nd	nd	nd	nd				
	160–325	Te	nd	85	5	10	+	+	++	Heavy Clay**
				Ombrogenous Peat Zone						
B- 5	0–395	P	610	nd	nd	nd				
	395–430	Te	61	80	5	15	+	++	++	Fine Clay
B-15	0–540	P	247	nd	nd	nd				
	540–560	Tt	33	80	5	15	–	+	+++	Heavy Clay
	560–600	Te	26	85	5	10	–	++	+	Heavy Clay**
				Riverine to Brackish Deposit Zone						
T-24***	80–150	P	11,800	nd	nd	nd				
	150–320	M	2,660	90	10	—	–	–	–	Light Clay
	320–434	M	622	75	10	15	+	+	++	Light Clay
	434–470	M	2,015	60	20	20	++	+	–	Light Clay
T-26	0–100	Tt	nd	70	15	15	++	++	–	Clay Loam
	100–420	Sd	nd	65	20	15	++	++	+	Sandy Clay Loam
	420–520	M	nd	65	10	25	+++	++	+	Heavy Clay
L- 3	0– 34	Tt	412	70	10	20	++	+	+	Fine Clay
	34–379	M	3,475	70	15	15	++	–	+	Clay[†]
	379–500	Ti	3,350	60	15	25	+++	++	+	Clay[†]
	500–600	Ti	2,700	60	15	25	+++	++	+	Heavy Clay
				Brackish to Marine Deposit Zone						
L- 5	0–244	M	4,925	55	15	30	+++	++	+	Clay[†]
	244–600	Ti	3,967	60	15	25	+++	++	+	Clay[†]

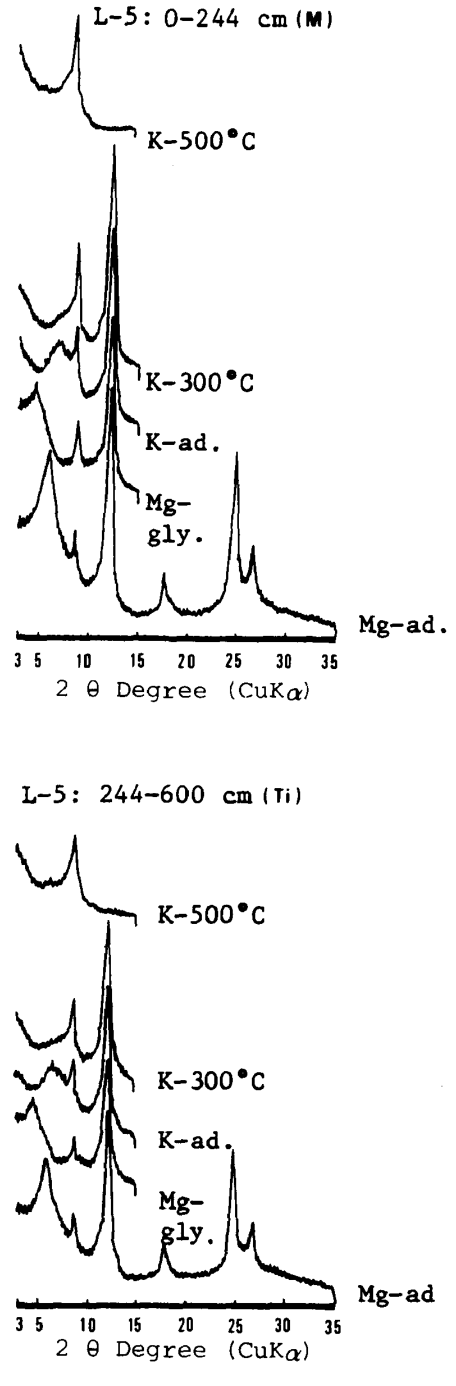
*Electric conductivity (soil water ratio of 1:5); **With red iron mottles; ***The first layer (0–80 cm) is derived from a canal excavation; [†]Alternating with fine sand.

M, Mangrove deposits; P, Peat; Te, Pleistocene terrace; Ti, Tidal flat; Tt, Fluviatile sediments; Sd, Sandy deposits; Sm, Smectite; V, Vermiculite; Al, Al-interlayered smectite and/or vermiculite; nd, not determined.

+, little; ++, moderate; +++, abundant; –, none.

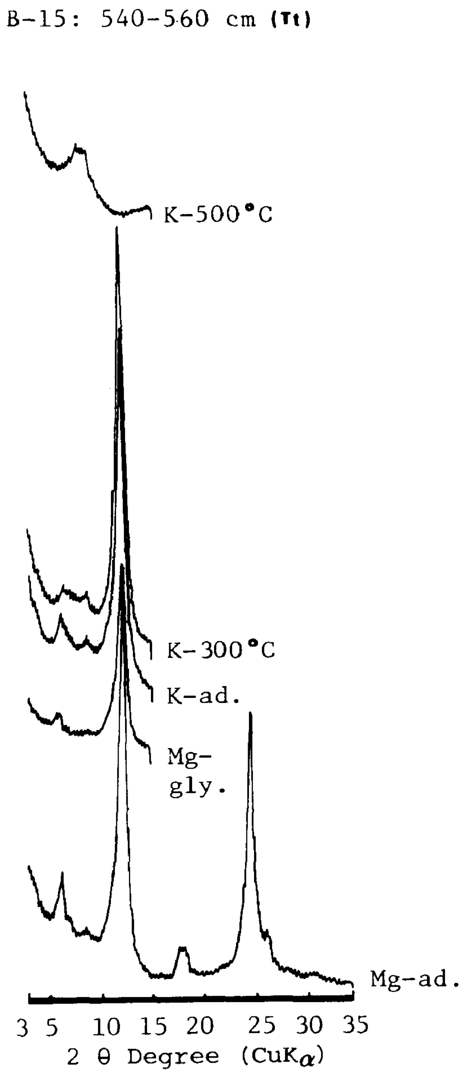


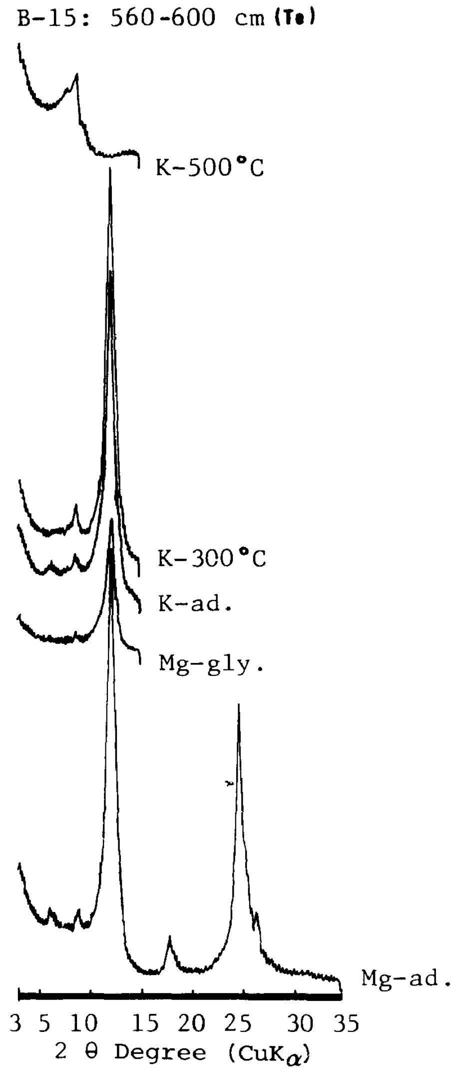
1-1 X-ray diffraction pattern of soil samples taken from two depths of profile B-2 of the mineral riverine deposit zone



1-2 X-ray diffraction pattern of soil samples taken from two depths of profile L-5 of the brackish to marine deposit zone

Fig. 1 Several X-ray Diffraction Patterns of Soil Samples Taken from Different Depths of Profiles on Each Physiographic Region of the Coastal Plain of Jambi





1-3 X-ray diffraction pattern of soil samples taken from two depths of profile B-15 of the ombrogeneous peat zone

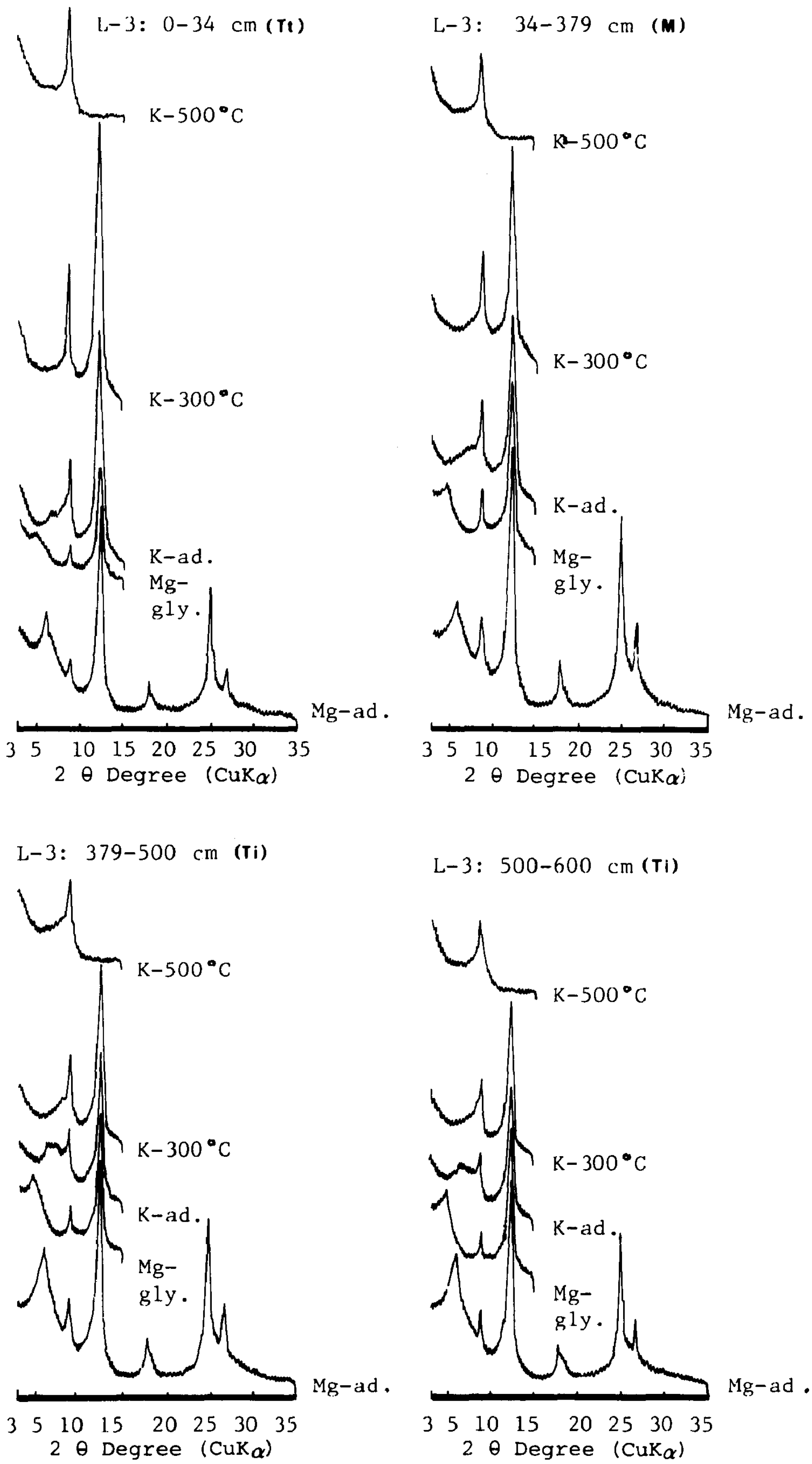
Fig. 1-Continued

Mineral riverine deposit zone. The sediments in the Profiles B-2 (all layers) and RTP-1 (at the depth of 0 to 44 cm) are recent levee materials of clayey texture and brownish to grayish color. These were categorized as fluviatile sediments (Tt). The grayish color in the bottom layers indicates that the sediments were often saturated by water.

The description of Profile B-2 is as follows:

1. 0– 20 cm Brownish black (10YR 3/2) light clay; little organic matter; massive, soft.
2. 20– 35 cm Grayish yellow and yellowish gray (2.5Y 6/2+2.5Y 6/1) light clay; massive, soft.
3. 35– 80 cm Olive gray and orange (2.5Y 6/1+7.5YR 6/6) light clay; massive, soft.
4. 80–180 cm Yellowish gray (2.5Y 6/1) light clay; massive, compact.

Below the recent levee materials, the Pleistocene terrace (Te) was found in the Profile



1-4 X-ray diffraction pattern of soil samples taken from four depths of profile L-3 of the riverine to brackish deposit zone

Fig. 1–Continued

RTP-1 at the depth of 160 to 325 cm. This terrace is characterized by heavy clay texture with abundant iron mottles and by firm to very firm consistence.

Fig. 1–1 shows the XRD of sediments taken from Profile B-2 at the depths of 0 to 35 and 35 to 180 cm. These soil samples are dominated by kaolin mineral (7.2 Å). Fig. 1–1 also shows that illite (10.1 Å) and the 14 Å minerals (14.3–15.0 Å) were present in all layers of these sediments.

The smectite in these sediments was found in the layers at the depth of 35 to 180 cm. Its presence is substantiated by a shift of the 14.9 Å peak of the air-dried Mg-clay to 18.4 Å for the glycerated Mg-clay.

The layers at the depth of 0 to 35 cm contain the 14 Å minerals, probably Al-interlayered smectite and/or vermiculite. The lower relative amount of illite in this layer than at the depth of 35 to 325 cm may indicate the weathering of illite to Al-interlayered smectite and/or vermiculite, although the homogenity of the parent materials is not proven.

The clay mineralogical composition of the Pleistocene terrace underlying the recent levee materials (see Profile RTP-1) is dominated by kaolin mineral (7 Å).

Ombrogenous peat zone. In Profile B-15 the sediments at the depth of 560 to 600 cm were judged during field study to be Pleistocene terrace (Te) [Supiandi 1988]. This terrace surface is covered by fluviatile sediments (Tr) (540 to 560 cm).

Fig. 1–3 shows the XRD of sediments taken from two depths of profile B-15. The clay mineralogical compositions of both Pleistocene terrace and fluviatile sediments are dominated by kaolin mineral which shows a broad peak at 7.2 Å.

In the sediments at the depth of 540 to 560 cm (Tt), the 14 Å minerals are Al-interlayered smectite and/or vermiculite. This might mean that the fluviatile sediments on the terrace were derived from terrestrial soil carried by the river.

Riverine to brackish deposit zone. The sediments in this zone taken from Profiles T-24, T-26 and L-3 consist of fluviatile sediments (Tt), mangrove deposits (M), and tidal flat deposits (Ti). Fig. 1–4 shows the XRD of sediments taken from four layers of Profile L-3.

The description of Profile L-3 is as follows:

1.	0– 13 cm	Dark reddish brown (5YR 3/2) peaty mineral.
2.	13– 34 cm	Grayish yellow brown (10YR 5/2) light clay; few plant remains; massive, soft.
3.	34– 63 cm	Grayish yellow (2.5Y 6/2) light clay; few plant remains; massive, soft.
4.	63–153 cm	Gray (5Y 5/1) heavy clay; few plant remains, wood blocks; massive, soft.
5.	153–231 cm	Gray (5Y 4/1) heavy clay; few plant remains; massive.
6.	231–379 cm	Alternating layers of dark grayish yellow and olive gray (2.5Y 5/2+5GY 5/1) light clay and dark greenish gray (10GY 4/1) fine sand; few plant remains, wood blocks; massive, soft.
7.	379–400 cm	Olive gray (5GY 5/1) light clay; massive, soft.
8.	400–500 cm	Alternating layers of olive gray (5GY 5/1) light clay and dark greenish gray (10GY 4/1) fine sand; few plant remains; massive, soft.

9. 500–600 cm Greenish gray (10GY 5/1) heavy clay; sea shells; massive, rather compact.

While the clay mineralogical composition of fluviatile sediment samples is dominated by kaolin mineral, smectite dominates the 14 Å minerals. This smectite might be high-charge type, for it collapses to 10.0 Å after K saturation. Small amounts of illite and Al-interlayered smectite and/or vermiculite were also found.

The clay mineralogical composition of mangrove deposits differs from that of fluviatile sediment. In these deposits, illite was slightly increased in amount while smectite was decreased (Table 1). Likewise, the presence of Al-interlayered smectite and/or vermiculite here is not obvious.

The tidal flat deposits (379 to 600 cm) show higher contents of 14 Å minerals than the fluviatile and mangrove deposits. The presence of smectite clearly indicates the influence of marine action. The source materials differ from those of the upper mangrove deposits.

Brackish to marine deposit zone. The sediments deposited here consist of mangrove deposits on tidal flat (M) and tidal flat deposits (Ti). Fig. 1-2 shows the XRD of sediments taken from two layers of Profile L-5. The description of Profile L-5 appears in Part I of this study [Supiandi 1988].

Fig. 1–2 and Table 1 indicate that the clay mineralogical composition of sediments in this zone is similar in all layers. Although these sediments show a predominance of the kaolin mineral, illite and smectite also occur.

At the depth of 0 to 244 cm, the relative amount of 14 Å minerals, which are dominated by smectite, is higher than that at the depth of 244 to 600 cm. The smectite probably derives from deposition when brackish water overflows onto the soil surface at high tide.

It contrast to the clay mineral in the riverine deposit and ombrogenous peat zones, the sediments in the brackish to marine deposit zone have a high amount of 2:1 type minerals (see Table 1). Marine and brackish environments probably play an important role in the accumulation and preservation of 14 Å minerals.

South Kalimantan

Table 2 presents the clay mineralogical composition of sediments from two physiographic zones. It indicates that the sediments in these zones have a similar clay mineralogical composition, in which kaolin mineral (7.2 Å) is dominant, but 14 Å minerals are more abundant than in the Jambi region.

Riverine to brackish deposit zone. In this zone, the samples were taken from three profiles (Profiles BM-26, BM-27 and BM-41). The sediments here are categorized as mangrove deposits (M), except for the sediments deposited in the upper layer of Profiles BM-26 and BM-27 at the depth of 0 to 85 cm. The last can be categorized as riverine deposits. The mangrove deposits are sometimes covered by peat deposits, as in Profile BM-41. Fig. 2–2 and 2–3 show the XRD of sediments form Profile BM-41 and BM-27. These profiles were described in Part I of this study [Supiandi 1988].

All layers of sediments are rather uniform in terms of clay types, which are dominated by kaolin mineral (7.2 Å). Illite (10.2 Å) and 14 Å minerals also occur. This last includes vermiculite, smectite and Al-interlayered smectite and/or vermiculite. The presence of vermiculite is characterized by the appearance of the 14 Å peak after glyceration of Mg-clay. The Al-

Table 2 The Clay Mineralogical Composition of Sediments from the Study Area of South Kalimantan

Pro-file	Depth (cm)	Strati-graphic Type	EC* (μmho/cm)	Mineralogical Composition						Texture
				7 Å	10 Å	14 Å	Sm	V	Al	
				----------(%)----------						
				Riverine to Brackish Deposit Zone						
BM-27	0– 85	Tt	2,220	55	10	35	++	++	–	Clay
	85–210	M		55	15	30	++	++	+	Clay
	210–265	M		60	10	30	++	++	+	Clay
	265–500	M		60	10	30	++	+	++	Clay
	500–600	M		60	10	30	++	+	++	Clay
BM-26	0– 43	M	2,220	50	5	45	++	++	–	Clay
	43– 85	M		50	10	40	++	++	–	Clay
	85–240	M		60	15	25	++	++	+	Clay
	240–376	M		60	15	25	++	+	++	Clay
	376–600	M		55	15	30	++	+	++	Clay
BM-41	0–194	P	1,580	nd	nd	nd				
	194–331	M		60	15	25	+	+	++	Clay
	331–453	M		60	15	25	+	+	++	Clay
	453–500	PM		nd	nd	nd				
	500–600	M		55	10	35	++	++	+	Clay
				Brakish to Marine Deposit Zone						
BM-11	0–108	P	2,000	nd	nd	nd				
	108–300	M		50	15	35	+	+	++	Fine Clay
	300–569	Ti		45	15	40	++	++	+	Fine Clay**
	569–600	Ti		45	15	40	++	++	–	Fine Sand***
BM- 8	0– 8	M	nd	60	10	30	+	++	++	Clay
	8– 58	M		65	10	25	+	++	++	Fine Clay
	58–112	M		60	10	30	+	++	++	Fine Clay
	112–200	Ti		50	10	40	+	+	++	Fine Clay**
	200–337	Ti		50	15	35	+++	+	–	Fine Sand***
	337–464	Ti		50	15	35	+++	+	–	Fine Clay**
	464–545	Ti		50	15	35	+++	+	–	Fine Clay**

*Electric conductivity of water samples (after Indonesia, Soil Research Institute [1973]); **Alternating with fine sand; ***Alternating with fine clay.

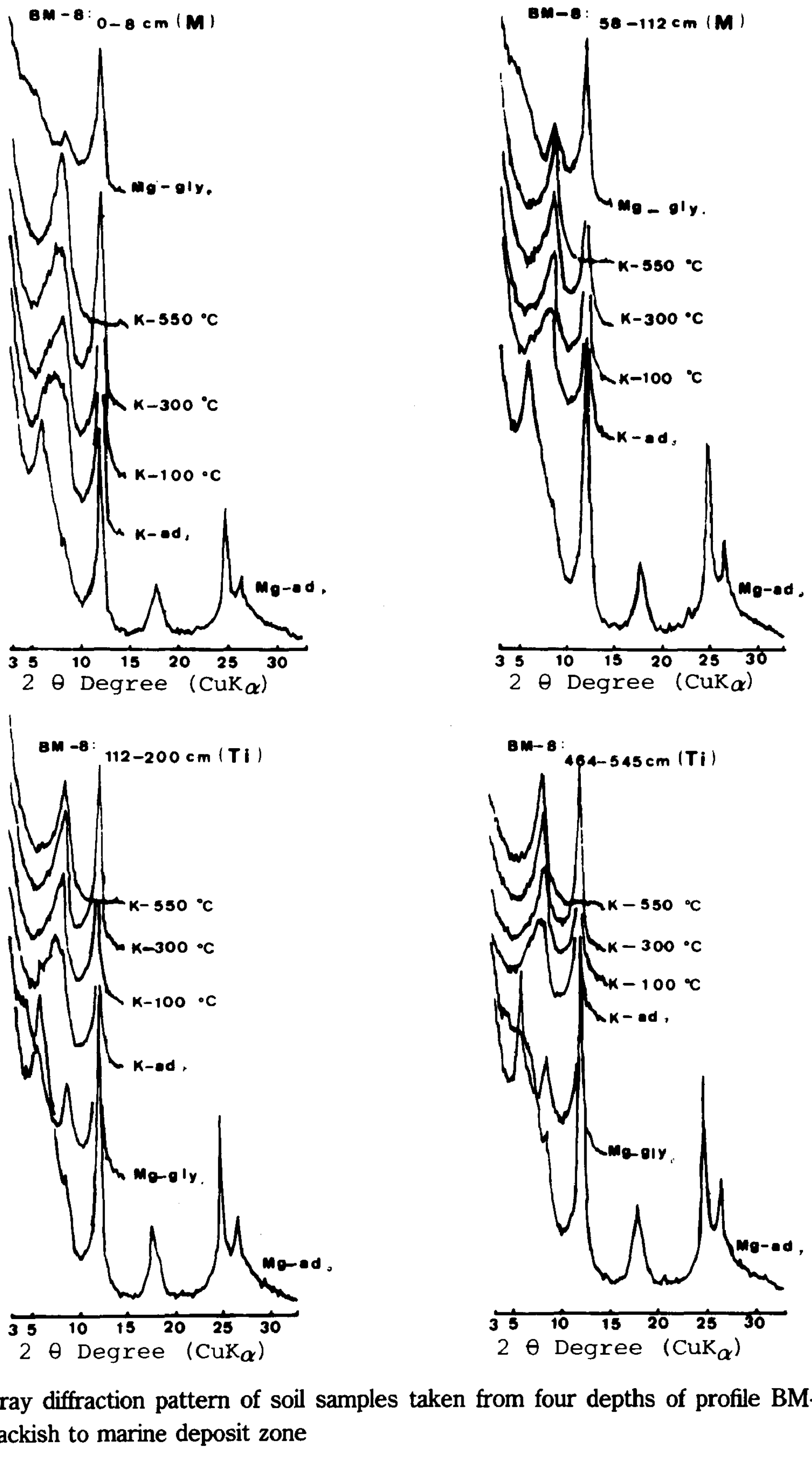
M, Mangrove deposits; P, Peat; PM, Peaty soil; Ti, Tidal flat; Sm, Smectite; V, Vermiculite; Al, Al-interlayered smectite and/or vermiculite; nd, not determined.

+, little; ++, moderate; +++, abundant; –, none.

interlayered smectite and/or vermiculite may be a weathering product of vermiculite and smectite.

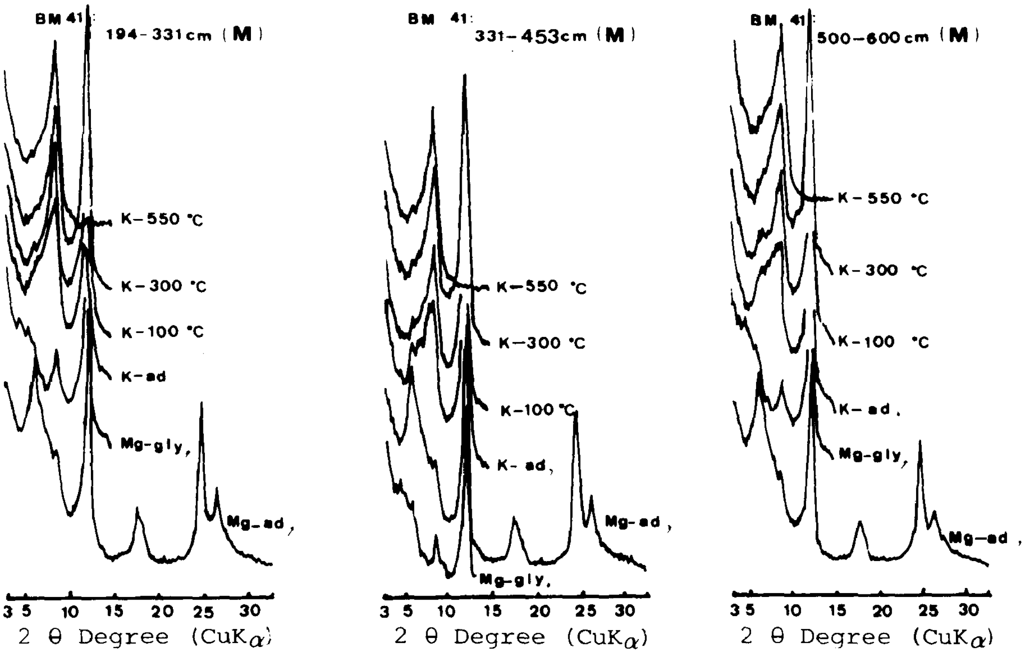
Table 2 shows that the proportion of 14 Å minerals in Profile BM-41 is lower than in Profiles BM-26 and BM-27. Peat deposits found in Profile BM-41 may cause the increase of acidity, which would cause the weathering of 14 Å minerals to kaolin mineral. This supposition is supported by the fact that at the depth of 500 to 600 cm of Profile BM-41, 14 Å minerals again increase to about 35 percent.

The quantity of 14 Å minerals in the upper layer of Profiles BM-26 and BM-27 at the depth of 0 to 85 cm is higher than at the depth of 85 to 600 cm. Also, Fig. 2–3 shows that Al-interlayered mineral occurs at the depth of 210 to 265 cm and of 500 to 600 cm of Profile BM-27, but that it is absent at the depth of 0 to 85 cm. This clearly indicates that the geomor-

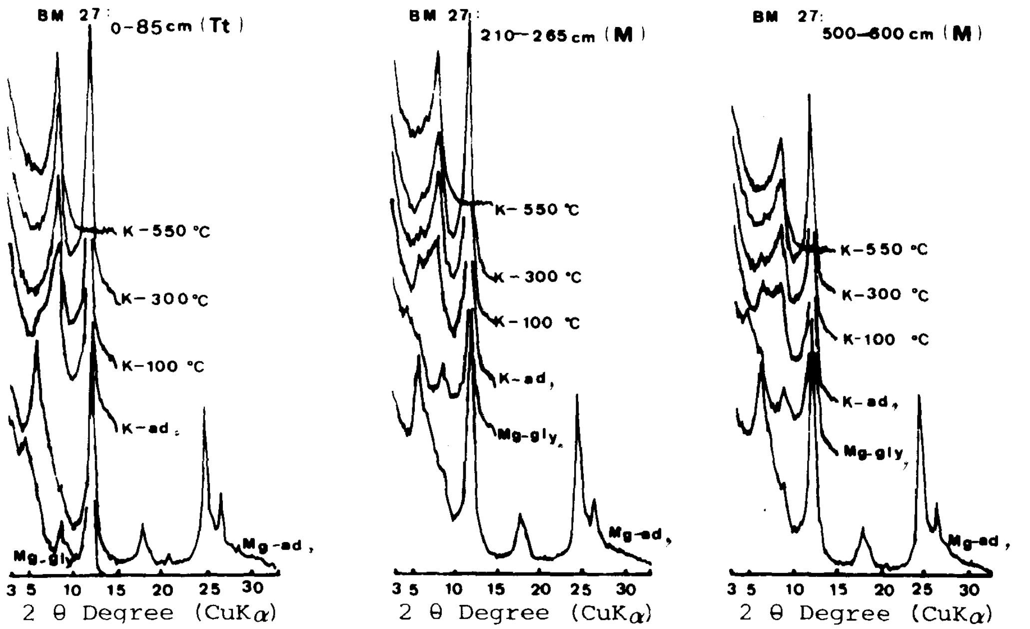


2-1 X-ray diffraction pattern of soil samples taken from four depths of profile BM-8 of the brackish to marine deposit zone

Fig. 2 Several X-ray diffraction Patterns of Soil Samples Taken from Different Depths of Profiles in Each Physiographic Region of the Coastal Plain of South Kalimantan



2-2 X-ray diffraction pattern of soil samples taken from three depths of profile BM-41 of the riverine to brackish deposit zone



2-3 X-ray diffraction pattern of soil samples taken from three depths of profile BM-27 of the riverine to brackish deposit zone

phic process involved in sedimentation of the upper layers (0 to 85 cm) is different from that in the bottom layers (85 to 600 cm).

Brackish to marine deposit zone. The sediments in this zone consist of mangrove deposits (M) and tidal flat deposits (Ti). Mangrove deposits are sometimes covered by thin peats as shown by Profile BM-11 (Table 2). Below the tidal flat deposits, a sand beach was found, as shown by Profile BM-8. This was described in Part I of this study [Supiandi 1988].

Fig. 2–1 shows the XRD of sediments taken from four depths of Profile BM-8. Based on the clay mineralogical composition (Table 2), these sediments can be divided into three layers as follows.

First: the layer at the depth of 0 to 112 cm, which is characterized by a high content of kaolin mineral (60 to 65 percent). The sediments in this layer can be categorized as mangrove deposits.

Second: the layer at the depth of 200 to 545 cm, which is characterized by a lower amount of kaolin mineral of about 50 percent. The sediments in this layer can be categorized as tidal flat deposits. The illite (10 Å) and 14 Å mineral contents of these deposits are higher than those of the mangrove deposits. Smectite tends to dominate the 14 Å minerals in the tidal flat deposits, as is substantiated by a shift of the 14–15 Å peak of the air-dried Mg-clay to about 18 Å peak for glycerated Mg-clay. This clearly indicates that in the upper layer (0 to 112 cm), the environment became acidic due to the oxidation of pyrites, and this caused the weathering of 14 Å minerals to kaolin mineral. In the bottom layer (200 to 545 cm), where the sediments are always saturated by water, the 14 Å minerals were preserved.

Third: the layer at the depth of 112 to 200 cm, which is characterized by the occurrence of Al-interlayered smectite and/or vermiculite. This layer can probably be categorized as a transitional layer between the unweathered sediments in the bottom layer and the weathered sediments in the upper layer. This means that although the 14 Å minerals in this transitional layer had begun to be weathered to Al-interlayered smectite and/or vermiculite, they were not yet transformed to kaolin mineral. We did not analyze the clay mineralogical composition at the depth of 545 to 600 cm, because this layer consists of sand beach deposits.

Profile BM-11 shows a rather different pattern from Profile BM-8, indicating that the sediments below the peat deposits consist of two layers. *First*: the layer at the depth of 108 to 300 cm, which is categorized as mangrove deposits. *Second*: the layer at the depth of 300 to 600 cm, which is categorized as tidal flat deposits. In the tidal flat deposits, the 14 Å mineral content is higher than in the mangrove deposits. Even though the mangrove deposits here are always saturated by water, the acid environment produced by the decomposition of organic matter caused the 14 Å minerals to be weathered to kaolin mineral.

The results of this investigation indicate that each geomorphic unit in the coastal plains of Jambi and South Kalimantan is different in terms of clay mineralogical composition. In Jambi, the fluviatile sediments and the Pleistocene terrace underlying the thick peat-dome are dominated by 1:1 type clay minerals (7.2 Å). The higher amount of 1:1 type clay minerals in the Pleistocene terrace underlying the deep peat than in that underneath the recent levee materials may indicate that the acid environment caused by organic acid influences the transformation of clay mineralogical composition. The recent sediments in uplifted tidal flats and mangrove deposits contain relatively higher amounts of the 14 Å minerals than the Pleistocene terrace, and this indicates that the marine environment clearly influences the clay mineralogical composition to preserve the 14 Å minerals. In the fluviatile sediments, the 14 Å minerals are Al-interlayered smectite and/or vermiculite, which were probably derived from terrestrial soils.

Although the recent sediments of tidal flat and mangrove deposits in South Kalimantan show a predominance of 1:1 type clay minerals, they contain appreciable amounts of 14 Å minerals. The presence of Al-interlayered minerals in the upper layer of mangrove deposits may indicate that the transformation of clay types also occurs here.

Factors Controlling the Formation of Clay Mineralogical Composition

From the results presented above, the composition of clay minerals in the coastal plains of Jambi and South Kalimantan appear to have been influenced by three controlling factors: (1) sediment source, (2) acid environment, and (3) marine environment.

Sediment Source

Tables 1 and 2 indicate that the sediments from the coastal plains of Jambi differ in their clay mineralogical composition from those of South Kalimantan. In Jambi, the kaolin mineral (7 Å) content is higher than in South Kalimantan, while the 14 Å mineral content is lower. These differences may be attributed to the difference in the sediment sources.

In the coastal plain of South Kalimantan, the weathering products were brought in by the Barito river. The weathering bedrock contains schists, graywackes and sandstone in association with the older eruptive rocks such as porphyrites, peridotites, gabbro, diabase, diorite, andesite and granite [Indonesia, Soil Research Institute 1973]. The schists and graywackes are produced by regional metamorphism and consist chiefly of micaceous minerals. Through the weathering process, these minerals were probably then transformed to 14 Å minerals. As a result, although the clay types of sediments in the coastal plain of South Kalimantan are dominated by kaolin mineral, they contain appreciable amounts of illite and 14 Å minerals.

On the contrary, the sediments in the coastal plain of Jambi are derived from a Plio-Pleistocene formation containing leached red-yellow soils in the upper layer (see Part I of this study). These sediments show a predominance of the 1:1 type clay minerals [Furukawa 1980], and this is why kaolin mineral dominates in the coastal plain of Jambi. Only in the sediments of the brackish to marine deposit zone (near the coastline) are 14 Å minerals found in appreciable amounts.

Acid Environment

One of the most outstanding features of the coastal plain of Jambi is the extensive occurrence of deep peat, while in South Kalimantan pyrite occurs extensively in mangrove deposits. As a result of the decomposition of peat and the oxidation of pyrite, the environment is acidified, and this influences the transformation of clay.

Peat deposits. The transformation of clay in the peat-capped deposits was probably induced by the acid reaction derived from organic acid. Table 3 shows that the soil pHs of peat vary from 2.0 to 3.9 and are mostly less than 3.7. This causes the soil pHs of sediments below peat deposits to be decreased. For instance, the soil pHs of sediments taken from Profile B-1 are higher than those from Profile B-15 (below peat deposits), although both sediments belong to the same Pleistocene terrace. On the

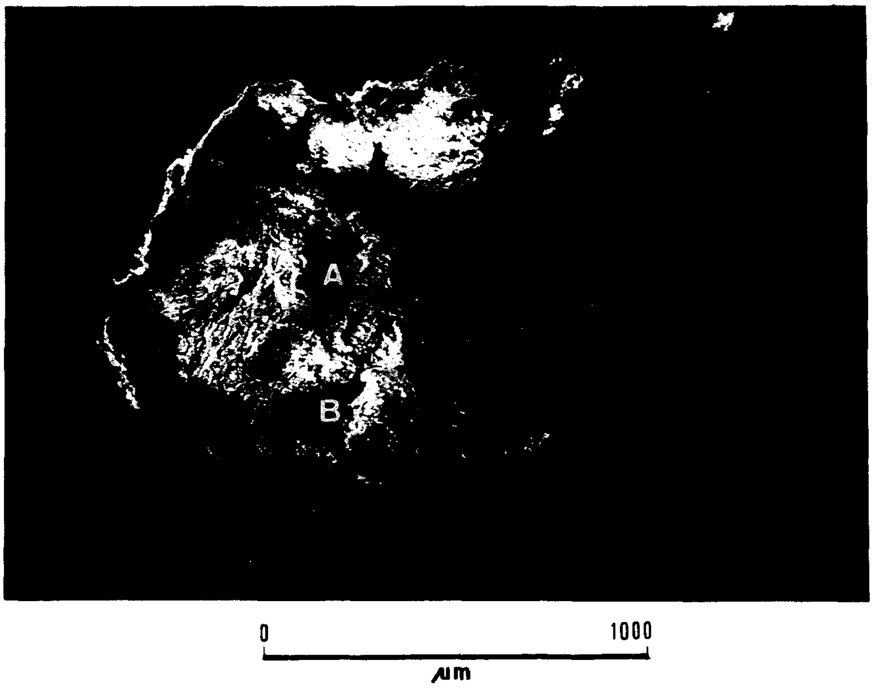
Table 3 Soil pHs and Ash Content of Peat and Mineral Soils, and Humification Degree (HC) of Peat Soil

No.	Profile	Depth (cm)	Soil	pH		HC* (%)	Ash Content** (%)
				H_2O	H_2O_2		
1.	B- 1	0– 50	Te	5.1	4.5	nd	90.73
		50– 80	Te	5.2	4.5	nd	93.64
		80–	Te	5.1	4.5	nd	94.08
2.	B- 8	0–138	P	3.9	nd	43.36	15.81
		138–162	Tt	4.3	4.0	nd	77.63
		162–347	P	3.7	nd	13.17	28.89
		347–418	Tt	4.5	3.0	nd	74.78
		418–532	Te	5.8	4.5	nd	89.49
3.	B-15	0– 24	P	3.4	nd	45.52	3.79
		24– 36	P	3.7	nd	66.77	3.16
		36– 73	P	3.6	nd	86.64	1.37
		73–100	P	3.3	nd	45.32	1.30
		142–230	P	3.4	nd	26.67	4.00
		230–305	P	3.4	nd	26.85	4.13
		305–343	P	3.6	nd	11.45	3.99
		343–372	P	3.5	nd	4.72	2.45
		372–540	P	3.6	nd	8.01	6.76
		540–560	Tt	4.7	3.5	nd	91.84
		560–600	Te	4.7	4.5	nd	92.98
4.	T-24	80–150	P	2.0	nd	25.85	32.07
		150–227	M	2.2	1.0	8.86	56.33
		227–263	M	2.7	1.0	nd	nd
		263–300	M	3.9	1.0	nd	nd
		300–320	M	5.0	1.5	nd	nd
		320–350	M	3.6	1.0	nd	nd
		350–365	M	4.0	1.5	nd	nd
		365–434	M	5.2	3.0	nd	nd
		434–441	M	5.5	3.0	nd	nd
		441–470	M	2.7	1.0	nd	nd

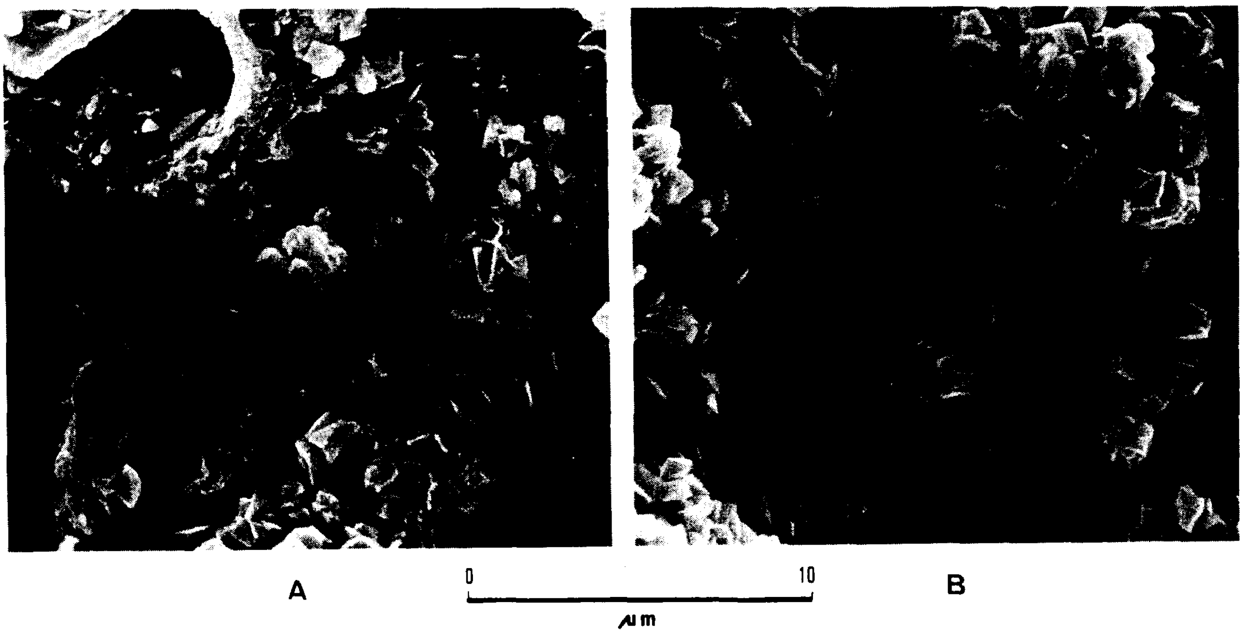
Note: The soil samples were taken from the coastal plain of Jambi.
*Based on colorimetric method [Kaila 1956]; **On oven dried-basis.
M, Mangrove deposits; P, Peat; Te, Pleistocene terrace; Tt, Fluviatile sediments; nd: not determined.

other hand, the kaolin mineral (7 Å) content of Profile B-15 is higher than that of Profile B-2 (near Profile B-1), while the sediments from Profile B-2 contain more illite and 14 Å minerals than those from Profile B-15. This suggests that the acid environment reduced the amounts of 14 Å minerals. This is supported by other data from Jambi (Profile B-5 and T-24) and from South Kalimantan (Profile BM-11 and BM-41). In all these profiles, the sediments below peat deposits show and increase of kaolin mineral (7 Å) and a decrease of 14 Å minerals.

Pyrite formation. Pyrite formation in the coastal plain of South Kalimantan was studied in order to clarify the relationship between the clay minerals in the sediments and the acid environment, which is caused by the pyrite oxidation. The pyrite accumulated here was found in the riverine to brackish deposit and brackish to marine deposit zones, which are situated in the Pulau Petak Delta area. Pyrite occurs mostly in the mangrove deposits on the tidal flat, and according to a report by the Soil Research Institute, Indonesia [1973] it covers about 46,250 ha or 22.1 percent of the total area of the Pulau Petak Delta. This pyrite is mostly associated with roots of mangrove vegetation (see Plate 1), and occurs mostly in the upper layers. This is rather different from Pons's finding [Pons 1973] that pyrite formation in tropical areas occurs mostly in vegetated tidal mud flats and is sustained by the organic matter



1–1 Plant root taken from mud clay deposits



1–2 The plant roots associated with the accumulation of secondary pyrites

Plate 1 The Scanning Electron Micrograph of pyrites Associated with Plant Root produced by mangrove vegetation. He categorizes the pyrite accumulation associated with plant remains as secondary pyrite. Thus, the pyrite formation found within the study area of South Kalimantan can also probably be categorized as secondary pyrite.

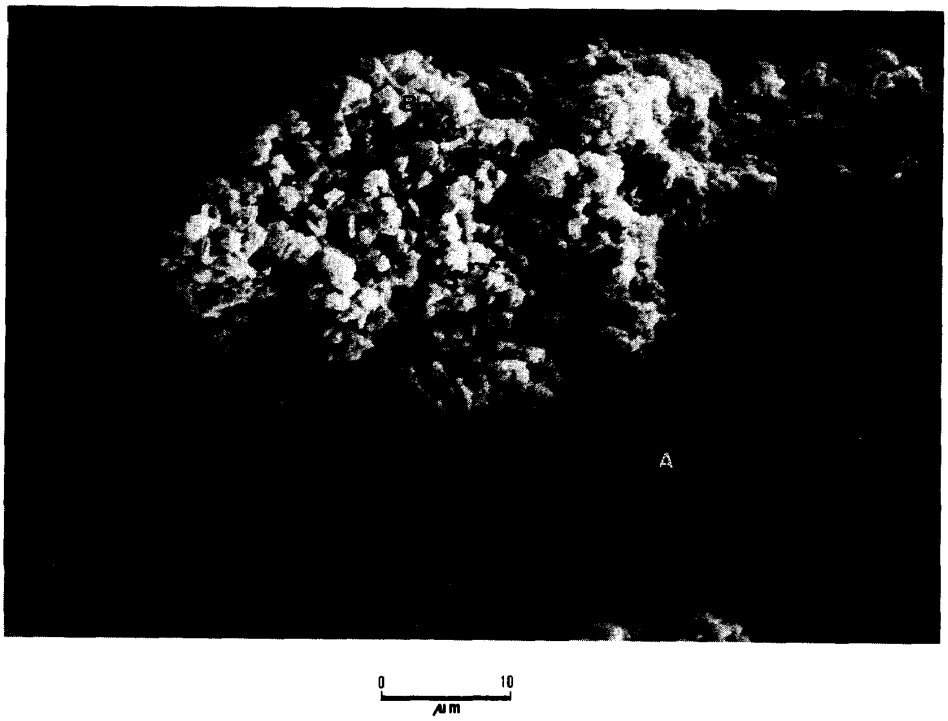
Today, a large part of the coastal plain of South Kalimantan has been exploited by local people and/or the government for settlement. As a result of drainage, the top soils become aerated and oxidized, leading to oxidation of pyrite causing a considerable drop in pH(H_2O) to below 4.0 (measured in the field). Another oxidation product is jarosite which is characterized by yellow mottles. Jarosite usually occurs as earthy yellow masses of individual grains, generally 0.1–0.5μm in diameter. Plate 2 shows a scanning electron micrograph of fresh jarosite associated with a gypsum crystal. The formation of this gypsum crystal is due to the drying of the soil, which caused the gypsum ($CaSO_4 \cdot 2H_2O$) to be precipitated.

The oxidation of pyrites is by the following reaction [van Breemen 1976]:

$$\text{Pyrite} + 15/4\ O_2 + 5/2\ H_2O + 1/3\ K^+ \dashrightarrow 1/3\ \text{Jarosite} + 4/3\ SO_4^{2-} + 3\ H^+.$$

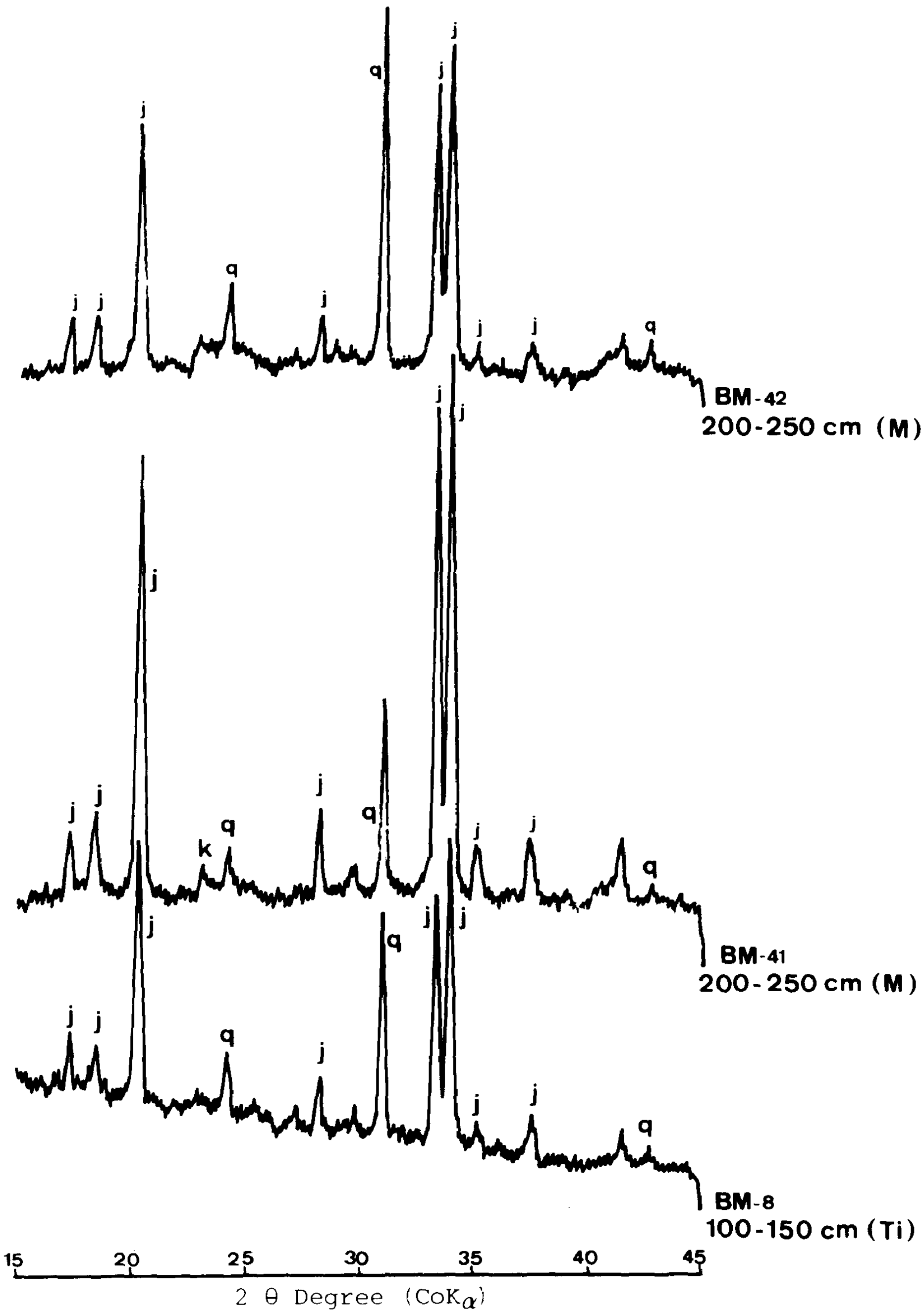
In all soil samples, the jarosite identified by X-ray diffraction using the CoK_α-radiation was categorized as a natrojarosite (Fig. 3 and Table 4).

In relation to clay transformation, Profile BM-8 (see Table 2) shows that the amount of kaolin minerals in the oxidation layer (0 to 112 cm) is higher than in the reduction layer. This may indicate that the strong acidity due to the oxidation of pyrite induces the weathering of illite and 14 Å minerals. In the reduction layer, however, pyrite was not oxidized, and the 14 Å minerals were preserved. The presence of the



A: Gypsum crystal B: Fresh jarosite

Plate 2 Scanning Electron Micrograph of Fresh Jarosite Associated with a Gypsum Crystal



j: Natrojarosite; q: Quartz; k: Kaolin mineral

Fig. 3 X-ray Diffraction Patterns of Oxidized Pyrites from the Study Area of South Kalimantan

oxidation layer is substantiated by the occurrence of bright brown (7.5YR 5/6) iron mottles.

Although we did not analyze pyrite in the coastal plain of Jambi, we are convinced that pyrite also occurs here in the mangrove deposits. This is supported by the evidence for pyrite in the field that the pHs (H_2O_2) of soil samples from mangrove deposits are mostly less than 2.0 (see Table 3 Profile T-24). The distribution of pyrite within the study area of

Table 4 Lattice Spacings (Å) of Jarosite from Light Yellow to Pale Yellow Mottles from Acid Sulfate Soil from South Kalimantan

Site and Depth (cm) of Soil Samples						Reference Patterns			
BM-8 100–150 5Y 8/4*		BM-41 200–250 5Y 8/3*		BM-42 200–250 2.5Y 7/4**		Jarosite†		Natro-Jarosite††	
d Å	Int.	d Å	Int.	d Å	Int.	d Å	Int.	d Å	Int.
5.95	22	5.95	13	5.95	17	5.93	45	5.95	20
5.56	19	5.56	17	5.56	17	5.72	25	5.59	30
5.05	86	5.05	82	5.05	74	5.09	70	5.06	80
3.67	19	3.66	18	3.66	18	3.65	40	3.667	12
3.11	82	3.11	90	3.11	88	3.11	75	3.122	90
3.06	100	3.06	100	3.06	100	3.08	100	3.066	100
—	—	—	—	—	—	3.02	6	—	—
2.96	11	2.966	12	2.966	11	2.965	15	2.963	12
2.78	16	2.78	13	2.78	11	2.861	30	2.793	16

*Pale yellow **Light yellow Int. = Intensity

†Based on The Joint Committee on Powder Diffraction Standards (JCPDS) (1972), Card No. 22–827. Jarosite is $KFe_3(SO_4)_2(OH)_6$.

††Based on JCPDS (1986), Card No. 36–425. Natrojarosite is $NaFe_3(SO_4)_2(OH)_6$.

Jambi was reported in detail by the Institut Pertanian Bogor (IPB) Team [1978]. This report shows that pyrites accumulated here at the depth of 0 to 50 cm and 50 to 100 cm only over respectively about 0.3 and 1.3 percent of the total extent of study area, and that it only occurs in a small, isolated area. The total extent of this study area, which covers the Berbak Delta, the Tanjung and the Kumpeh areas, is about 191,000 ha. Thus, the transformation of clay in the sediments of the coastal plain of Jambi was less influenced by the acid environment due to pyrite oxidation than by that due to organic acid. This fact is substantiated by the presence of extensive peat deposits covering more than 50 percent of the total area studied [IPB-Team 1978].

During field study in Jambi, we also found a few bright reddish brown (5YR 5/8) mottles, which were probably a mixture of hematite and goethite. Hattori made the same finding in the sediments of the Bangkok Plain [Hattori 1972].

Marine Environment

The marine environment in the coastal plains of Jambi and South Kalimantan can be divided into two types, namely, former and present marine environments. In Jambi, the former marine environment is substantiated by the presence of mangrove deposits on the terrace and on the tidal flat, and in South Kalimantan by the presence of mangrove deposits on the tidal flat. These mangrove deposits were deposited by the transgression and regression of the sea in the past. The present marine environment was found in the brackish to marine deposit zone of coastal plains near to the coastline.

In South Kalimantan, when the sea level rose during the Post-Glacial period, the riverine to brackish deposit and the brackish to marine deposit zones situated in the Pulau Petak Delta area were probably submerged by the sea. Therefore, the sediments deposited here were influenced by marine processes, causing an increase in the amount of 14 Å minerals (see Table 2). This is supported by the fact that all soil samples taken from the study area of South Kalimantan show a similar pattern of clay mineralogical composition, which is characterized by a high content of 14 Å minerals. This is interpreted as indicating that the sediments were deposited here contemporaneously during the past rise of the sea level, which is substantiated by the finding of mangrove deposits which sometimes alternate with fine sand over almost all of the study area (see Part I of this study).

In the study area of Jambi, the sea covered the area up to the Dendang river in the Post-Glacial period, and thus the sediments deposited here were partly influenced by marine processes. This is substantiated by the presence of mangrove deposits distributed from the Dendang river to the coast as shown in Part I of this study [Supiandi 1988]. Table 1 also shows that the relative amounts of clay minerals in all layers of sediments deposited in the brackish to marine deposit zone were similar to those in the bottom layer of the riverine to brackish deposit zone, showing the influence of marine processes during the Post-Glacial period.

The deposition processes under the present marine environment in the brackish to marine deposit zone of the coastal plains of Jambi and South Kalimantan were mostly influenced by tide and wave actions. The sediments deposited here are mostly covered by the present mangrove vegetation, although part of this zone has been exploited by local people for coconut plantation. In Jambi, these sediments show higher contents of 14 Å minerals than sediments in other zones, while in South Kalimantan (Pulau Petak Delta area) the contents of 14 Å minerals of sediments are similar throughout the study area.

Thus, the marine environment clearly influences the clay mineralogical composition by preserving a high content of illite and 14 Å minerals.

Conclusion

The transformation of clay in the sediments was caused by landform development. In Jambi, the landform development was caused by: (1) the upgrowth of peat deposits on the Pleistocene terrace and on the recent sediments, (2) the accretion of coastline by deposition of recent sediments, and (3) the formation of recent levees near the river by deposition of fluviatile sediments. Although the Pleistocene terrace clearly shows a predominance of the 1:1 type clay mineral (7 Å), the sediments covering this terrace as the result of riverine deposition show relatively high contents of illite and 14 Å minerals. Since these riverine deposits (fluviatile sediments) originated as weathering products brought from the hinterland by the Batang Hari river, the 2:1 type clay minerals in the recent levee materials did not develop *in situ*.

On the Pleistocene terrace, ombro-peat also developed. The fluviatile sediments underlying the peat were then attacked by organic acids. This caused the 2:1 type clay mineral to be transformed to kaolin minerals. The transformation of the 2:1 type to 1:1 type clay mineral is also found in the recent sediments that are covered by peat.

The recent mangrove sediments on the terrace and on the tidal flat contain prominent amounts of illite and 14 Å minerals. Since the marine environment preserves the 2:1 type minerals, this clearly indicates that these sediments were deposited by sediment supply of riverine and marine origin, and by the transgression and regression of the sea in the past.

The landform development in South Kalimantan was caused by; (1) the upgrowth of peat deposits on recent sediments and on sand and gravel, (2) the accretion of coastline by deposition of recent sediments, and (3) the formation of recent levee materials near the river by deposition of fluviatile sediments. These recent sediments are uniform in terms of clay types. This may indicate that the transformation of clay is limited to a very small range of types, because the marine environment during the transgression period influenced the sediments to preserve the 14 Å minerals. The transformation of clay type took place only in the oxidation layers and in the sediments underlying the peat deposits. In the oxidation layers, oxidation products of pyrites acidified the environment. Likewise, the sediments underlying peat became acidified as the result of organic matter decomposition. The acid environment caused the 2:1 type clay mineral to be transformed to Al-interlayered smectite and/or vermiculite and to kaolin mineral.

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